MSFC-463

IAC-07- -D1.5.01

The MSFC Systems Engineering Guide: An Overview & Plan

Jerry Shelby
NASA/Marshall Space Flight Center, United States
Jerry.Shelby@nasa.gov
L. Dale Thomas
NASA/Marshall Space Flight Center, United States
dale.thomas@nasa.gov

ABSTRACT

As systems and subsystems requirements become more complex in the pursuit of the exploration of space, advanced technology demands an integrated approach to the design and development of safe and successful space systems. System engineers play a vital and key role in transforming mission needs into space system requirements that can be verified and validated. This results in a safe and cost effective design that satisfies the mission schedule.

A key to successful system design within systems engineering is communication. Communication, through a systems engineering infrastructure, not only ensures that customers and stakeholders are satisfied but assists in identifying space system requirements; i.e. identification, integration and management. This system design will produce a spacecraft, vehicle, scientific instrument, or other system/subsystem that is verifiable, traceable, and effectively satisfies cost, schedule, performance, and risk throughout the life-cycle of the product.

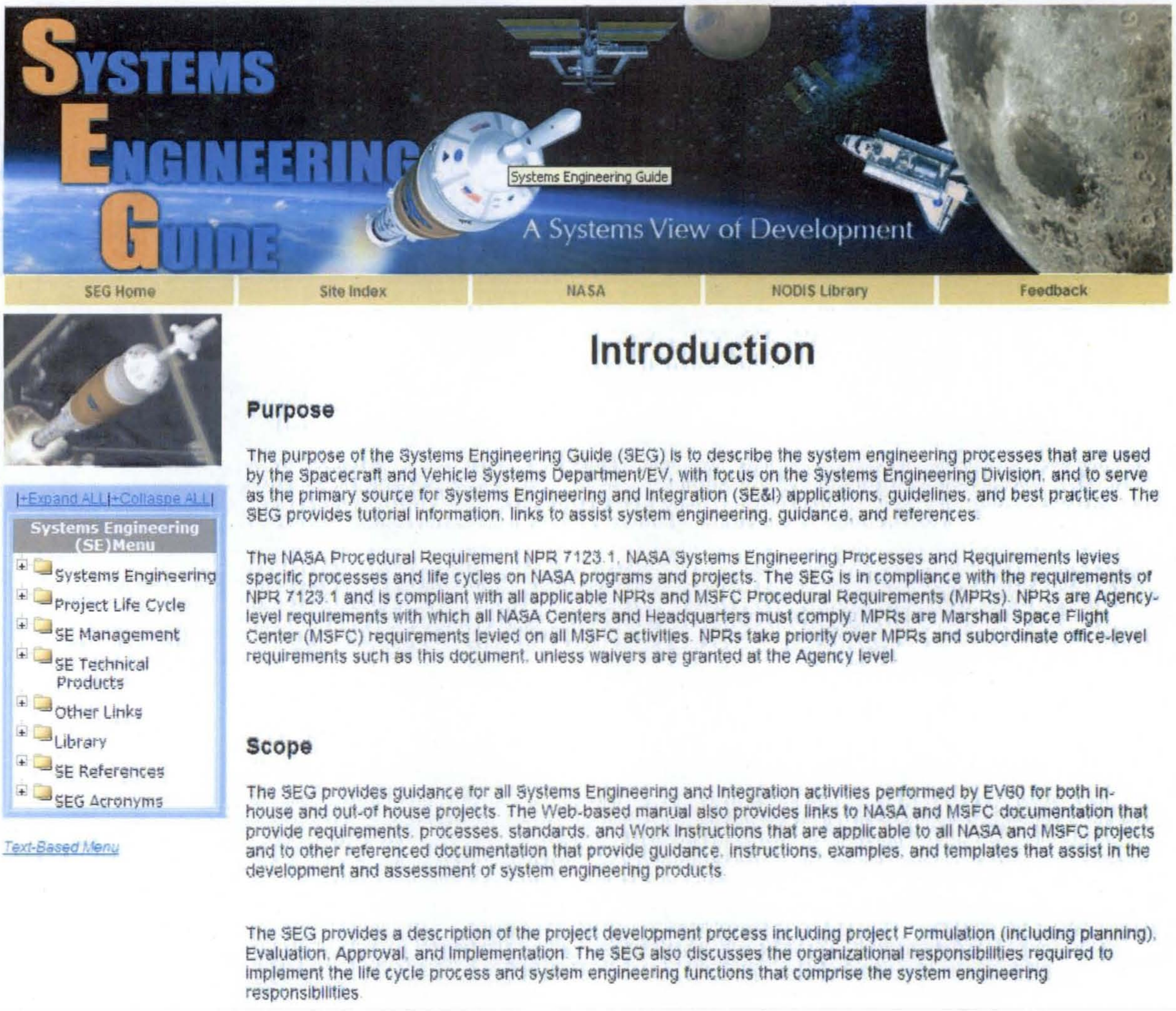
A communication infrastructure brings about the integration of different engineering disciplines within vehicle design. A system utilizing these aspects enhances system engineering performance and improves upon required activities such as Development of Requirements, Requirements Management, Functional Analysis, Test, Synthesis, Trade Studies, Documentation, and Lessons Learned to produce a successful final product.

This paper describes the guiding vision, progress to date and the plan forward for development of the Marshall Space Flight Center (MSFC) Systems Engineering Guide (SEG), a virtual systems engineering handbook and archive that describes the system engineering processes used by MSFC in the development of ongoing complex space systems such as the Ares launch vehicle and forthcoming ones as well. It is the intent of this website to be a "One Stop Shop' for MSFC systems engineers that will provide tutorial information, an overview of processes and procedures and links to assist system engineering with guidance and references, and provide an archive of relevant systems engineering artifacts produced by the many NASA projects developed and managed by MSFC over the years.

Background

Systems engineering utilizes an interdisciplinary approach to the design of a system[1]. This interdisciplinary approach requires communication, integration, and successful application of engineering techniques from many engineering disciplines and engineering specialty groups across teams and organizations. The objective of systems engineering is to ensure that the system to be realized will be designed, manufactured, successfully operated, and effectively satisfies cost, schedule, performance, and risk throughout the life-cycle of the product. To design a complex system such as a launch vehicle requires engineers from various technical disciplines in engineering. Many times these engineers basic focus is primarily within their own areas of interest (e.g. propulsion, avionics, structures, fluids and hydraulics, launch facility, spare parts, manufacturing, delivery, vehicle safety, crew safety, mission success, vehicle recovery etc.). The systems engineer's task is to unite these various technical disciplines together as a team to ensure that the system and subsystem products of these disciplines, when integrated, satisfies the user requirements, are cost effective, and satisfies the required system performance and risk throughout the intended life-cycle of the vehicle.

It is with this premise that the Systems Engineering Guide (SEG) has been developed at MSFC. The purpose of the SEG is to enable, disseminate, and construct an infrastructure of communications for systems engineering information at MSFC, utilizing and facilitating this interdisciplinary approach to system and subsystem design. The vision of the SEG is to promote the application of a systematic and disciplined systems engineering approach to space system design by providing tutorial information, an overview of processes and procedures, links to assist system engineering with guidance and references, and provide an archive of relevant systems engineering artifacts produced by the many MSFC projects, past and present. The resulting information will be contained on the SEG website (**Figure 1**) and available to management and systems engineers across the center.



Systems Engineering Guide (SEG) – Historical Research
Figure 1

To guide the SEG development and assure relevance to both ongoing and anticipated space system developments at MSFC, a SEG Board of Directors has been established. The board membership includes senior managers in the primary project areas including Space Shuttle, Ares Launch Vehicle, and Science & Mission Systems as well as senior managers in the MSFC Engineering Directorate. The board members recommend activities to be conducted, perform SEG development oversight, and provide overall supervision for the implementation of Systems Engineering (SE) processes at MSFC

System Engineering Guide Overview

The SEG concentrates in three specific areas to enable and advance communication in systems engineering at MSFC. These areas are:

1. **Common Technical Processes** – Provide communication across teams and organizations with "what" has to be done to engineer superior system products in projects and "why" (illustrated in **Figure 2**).

2. **Tools and Methods** –
   - *Provide an avenue of access* for SE teams across project boundaries and engineering disciplines to communicate efficiently and effectively with respect to advanced tools and methods established within projects (**Figure 2**).
   - *Provide links to references* such as NASA Systems Engineering Handbook (SP-6105) and other tutorial information of processes and procedures. These hyperlinks will include various SE references, internal and external to NASA (**Figure 3**).
   - *illustrate the effective use of the NASA project life cycle to system engineering* with guidance and references, and provide an archive of systems engineering artifacts produced by the many NASA projects developed and managed by MSFC over the years (**Figure 3**).
3. **Enhanced Systems Engineering Training** [4] – The SEG will be used as an educational tool to expand the knowledge of MSFC experienced system engineers, and perform as a tutorial to educate new hires within SE. The SEG will effectively communicate the NASA/MSFC methods, tools, and SE processes.

** These areas will be addressed in further detail in the discussion which follows.

[+Expand ALL|+Collaspe ALL]

Systems Engineering (SE)Menu

Systems Engineering

- SE Overall Function
- Systems Hierarchy
- SE and Integration
- NASA Project Life Cycles
- SE Technical Processes

Project Life Cycle
SE Management
SE Technical Products
Other Links
Library
SE References
SEG Acronyms

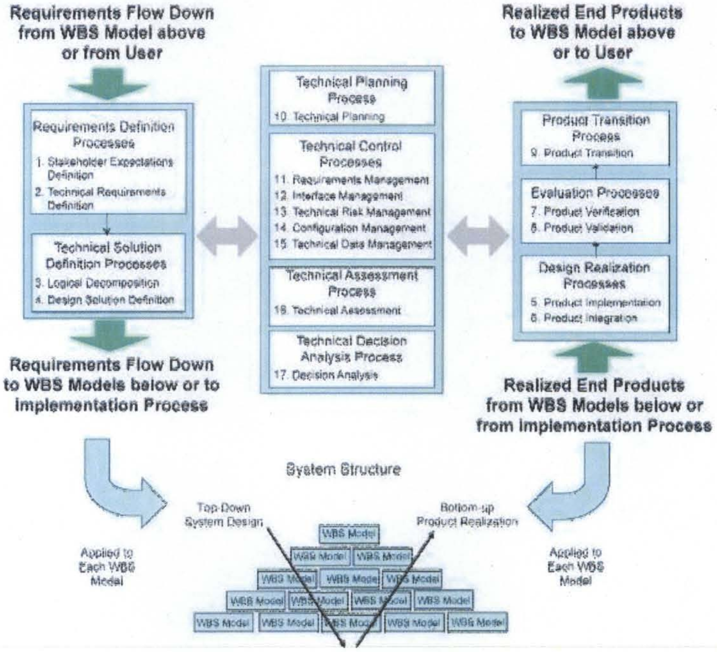
Text-Based Menu

Systems Engineering Technical Processes

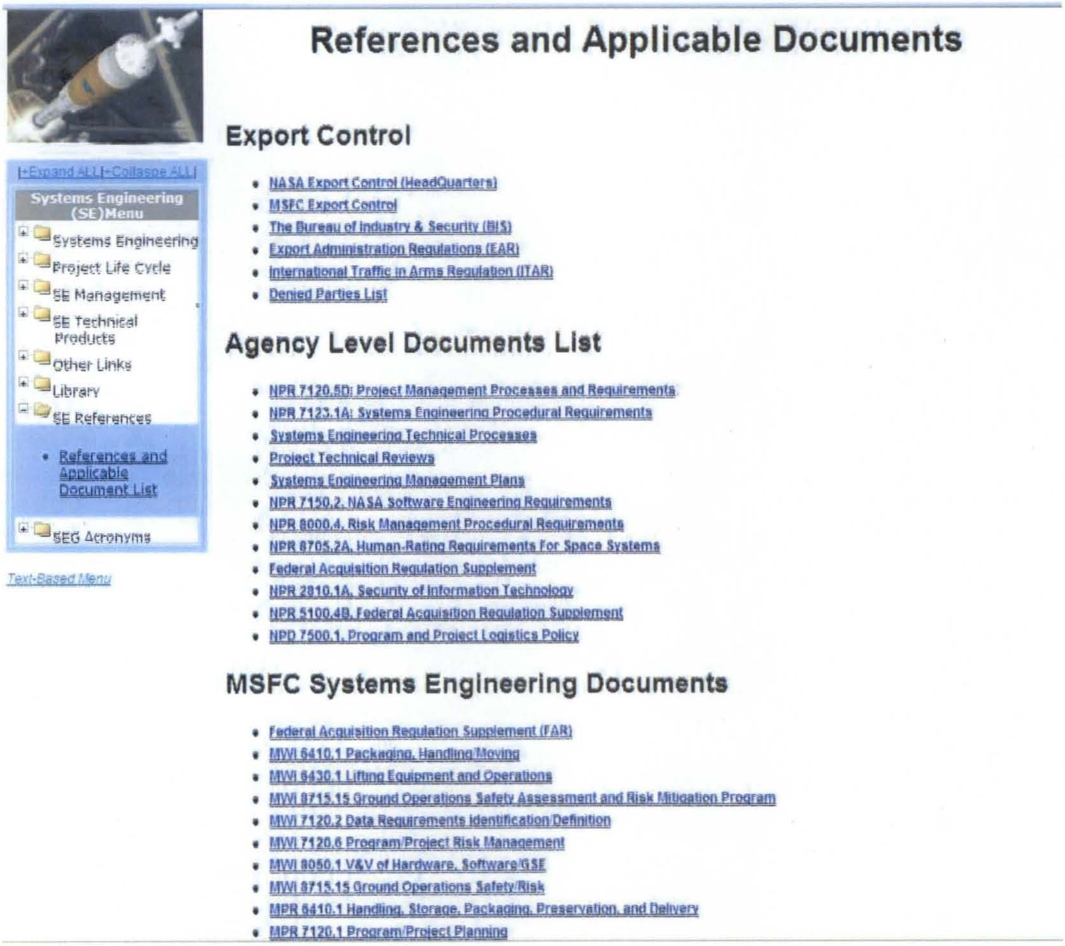
NPR 7123.1A establishes a core set of common technical processes and requirements to be used by NASA projects in engineering system products during applicable product-line life cycle phases to meet phase exit criteria and project objectives. The 17 common technical processes are enumerated according to their description. The SE common technical processes model illustrates the use of:

- (1) the system design processes for top down design of each product in the system structure,
- (2) the product realization processes for bottom up realization of each product in the system structure, and
- (3) the technical management processes for planning, assessing, and controlling the implementation of the system design and product realization processes and to guide technical decision making (decision analysis).

The common technical processes are applied to a product-based Work Breakdown Structure (WBS) model to concurrently develop the products that will satisfy the operational or mission functions of the system (end products) and that will satisfy the life cycle support functions of the system (enabling products). The enabling products facilitate the activities of system design, product realization, operations and mission support, sustainment, and end-of-product life disposal or recycling by having the needed products and services available when needed.



Common Technical Processes [2] (SEG)
Figure 2



References and Applicable Documents
Figure 3

Processes, Tools, & Methods

Stage-gate systems model product development as a process akin to a manufacturing process, and implements process controls to assure quality. They divide the development process into a predetermined set of stages, themselves consisting of prescribed, related, and often parallel activities, and each is usually more expensive than the preceding one. Space system design evolves from the abstract notion of a mission concept to an operational system. The technical work to be done in a system development includes the associated technical, support, and management tasks needed to generate the deliverable products and satisfy entry and success criteria of key technical events for the applicable system life-cycle management phase. The key technical events typically consist of reviews at the conclusion of a particular phase of the system life cycle, where the progress achieved during that phase is assessed against the plan and, together with the technical risks, a decision is made to proceed to the successive phase or to remain in the current phase for a finite duration (or possibly be terminated altogether for poor performance). Per NPR 7123, the key technical events and their temporal phasing with the system life cycle are identified and illustrated in **Figure 4**. Appendix G of NPR 7123 provides a description of review objectives, entry and success criteria.

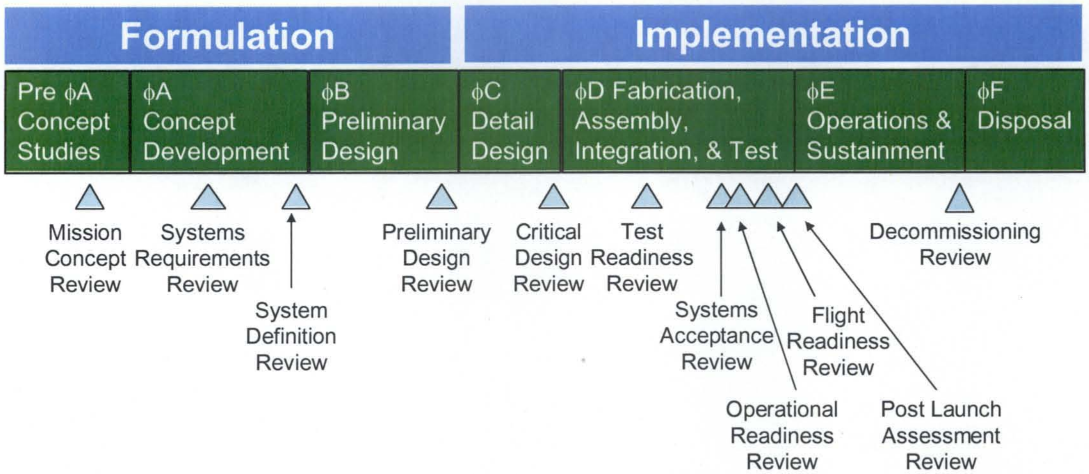
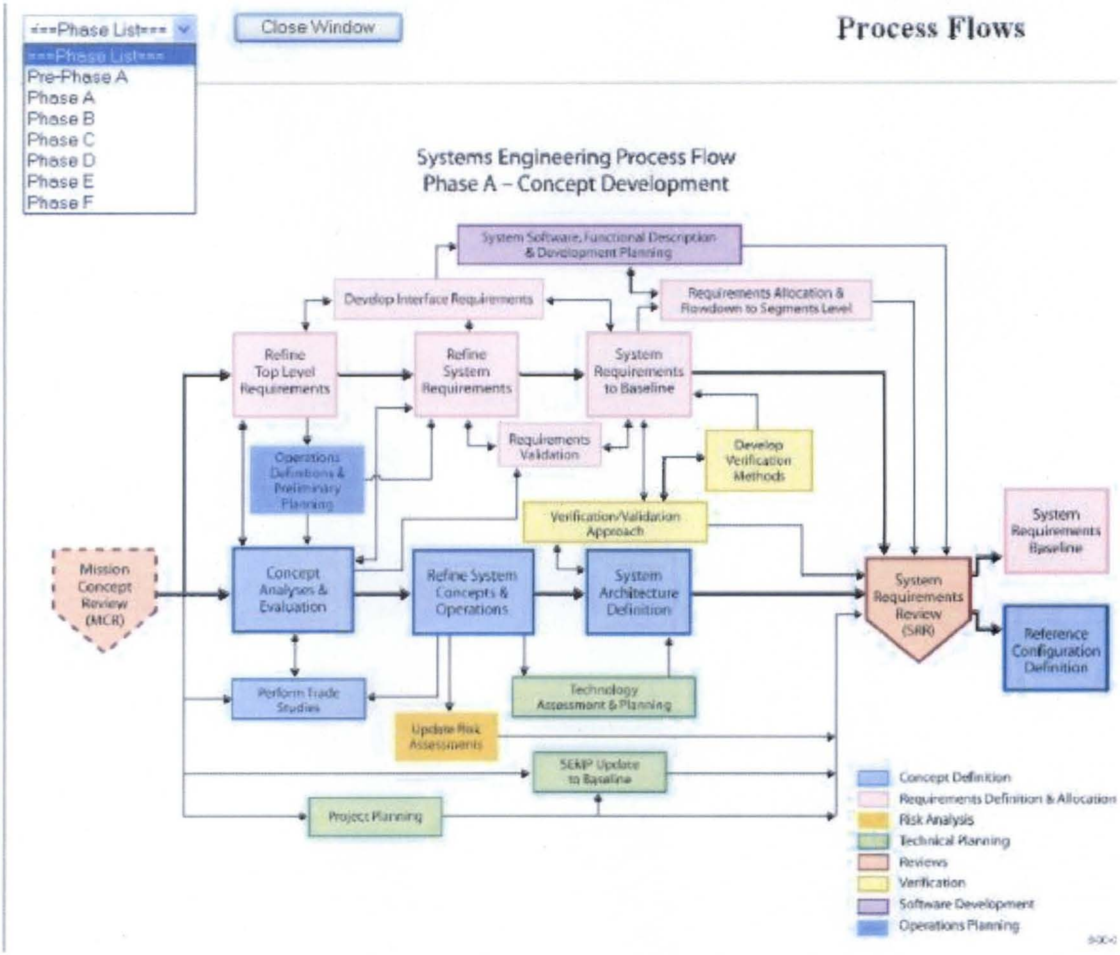


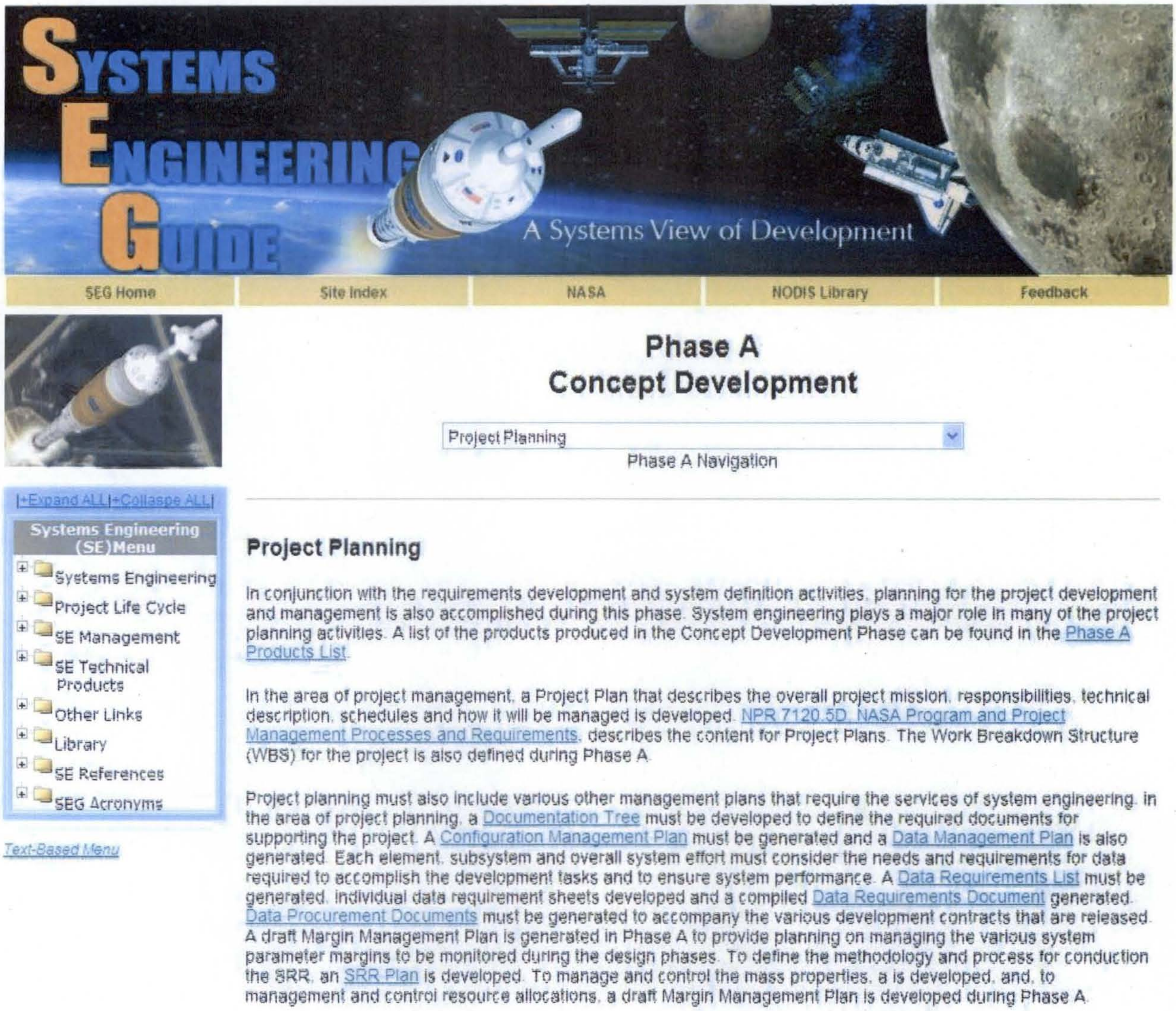
Figure 4 - Key Technical Events during the Flight System Life Cycle per NPR 7123. These key technical events constitute decision gates which must be successfully competed to continue progressing through the life cycle.

Each Phase of the product (i.e. launch vehicle design) consists of various activities that must be identified and well defined. Completion of these activities leads to successful satisfaction of Entrance Criteria and Exit criteria (Success Criteria) such that the space system development can progress to the next major milestone. As illustrated in Figure 2, NPR 7123 consists of 17 distinct processes grouped into three general categories: System Design Processes, Technical Management Processes, and Product Realization Processes. The activities associated with each process differ, sometimes subtly and sometimes significantly, over the phases of the life cycle. The SEG provides descriptions of the activities that comprise the 17 processes as tailored to each discrete phase of the product development cycle. Figure 5 illustrates the activities comprising the first half of Phase A (Concept Development) – the activities that commence upon successful completion of the Mission Concept Review and culminate in the Systems Requirements Review. Process descriptions exist or are under development for each segment of the life cycle



Systems Engineering Guide: Life Cycle Phase
Figure 5

The SEG describes of these Phase activities with hyperlinks. For example, when a systems engineer clicks the "Project Planning" activity in "Phase A", **Figure 5**, they will be taken to the Project Planning page within the SEG as illustrated in **Figure 6**. The Project Planning page lists pertinent references and expected technical artifacts (e.g. documentation tree, Systems Requirements Review Plan, etc.) contained within the "Project Planning" Phase when engaged in the Project Planning Process in Phase A. This type of information page is listed throughout the life cycle for each discrete activity within each Phase. And in turn, the Project Planning page contains hyperlinks to these technical artifacts (e.g. documentation tree, Systems Requirements Review Plan, etc.), to explain the "How and Why" of each products development. Actual examples of these technical artifacts are also provided as references. **Figure 7** illustrates the "how and why" of the Systems Engineering Management Plan (SEMP) as one example, including a hyperlink to the Ares Systems Engineering Management Plan.



SYSTEMS ENGINEERING GUIDE

A Systems View of Development

SEG Home | Site Index | NASA | NODIS Library | Feedback

|+Expand ALL|+Collapse ALL|

Systems Engineering (SE) Menu

- Systems Engineering
- Project Life Cycle
- SE Management
- SE Technical Products
- Other Links
- Library
- SE References
- SEG Acronyms

Text-Based Menu

Phase A
Concept Development

Project Planning

Phase A Navigation

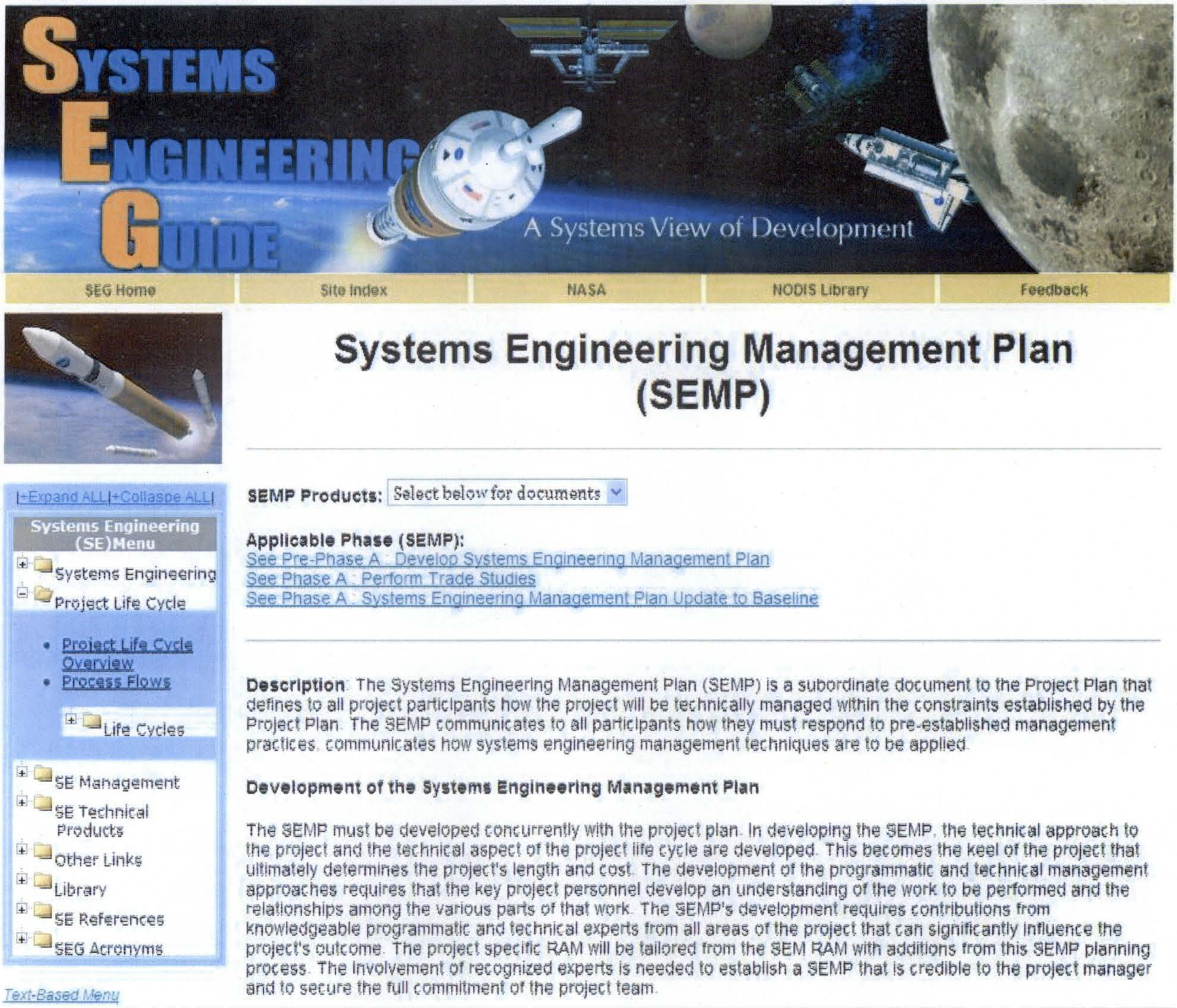
Project Planning

In conjunction with the requirements development and system definition activities, planning for the project development and management is also accomplished during this phase. System engineering plays a major role in many of the project planning activities. A list of the products produced in the Concept Development Phase can be found in the Phase A Products List.

In the area of project management, a Project Plan that describes the overall project mission, responsibilities, technical description, schedules and how it will be managed is developed. NPR 7120.5D, NASA Program and Project Management Processes and Requirements, describes the content for Project Plans. The Work Breakdown Structure (WBS) for the project is also defined during Phase A.

Project planning must also include various other management plans that require the services of system engineering. In the area of project planning, a Documentation Tree must be developed to define the required documents for supporting the project. A Configuration Management Plan must be generated and a Data Management Plan is also generated. Each element, subsystem and overall system effort must consider the needs and requirements for data required to accomplish the development tasks and to ensure system performance. A Data Requirements List must be generated, individual data requirement sheets developed and a compiled Data Requirements Document generated. Data Procurement Documents must be generated to accompany the various development contracts that are released. A draft Margin Management Plan is generated in Phase A to provide planning on managing the various system parameter margins to be monitored during the design phases. To define the methodology and process for conduction the SRR, an SRR Plan is developed. To manage and control the mass properties, a is developed, and, to management and control resource allocations, a draft Margin Management Plan is developed during Phase A.

Systems Engineering Guide: Project Planning Phase Activity
Figure 6



Systems Engineering Management Plan (SEMP)

|+Expand ALL|+Collaspe ALL|

Systems Engineering (SE)Menu

- Systems Engineering
- Project Life Cycle
  - Project Life Cycle Overview
  - Process Flows
    - Life Cycles
- SE Management
- SE Technical Products
- Other Links
- Library
- SE References
- SEG Acronyms

Text-Based Menu

SEMP Products: Select below for documents

Applicable Phase (SEMP):
See Pre-Phase A : Develop Systems Engineering Management Plan
See Phase A : Perform Trade Studies
See Phase A : Systems Engineering Management Plan Update to Baseline

Description: The Systems Engineering Management Plan (SEMP) is a subordinate document to the Project Plan that defines to all project participants how the project will be technically managed within the constraints established by the Project Plan. The SEMP communicates to all participants how they must respond to pre-established management practices, communicates how systems engineering management techniques are to be applied.

Development of the Systems Engineering Management Plan

The SEMP must be developed concurrently with the project plan. In developing the SEMP, the technical approach to the project and the technical aspect of the project life cycle are developed. This becomes the keel of the project that ultimately determines the project's length and cost. The development of the programmatic and technical management approaches requires that the key project personnel develop an understanding of the work to be performed and the relationships among the various parts of that work. The SEMP's development requires contributions from knowledgeable programmatic and technical experts from all areas of the project that can significantly influence the project's outcome. The project specific RAM will be tailored from the SEM RAM with additions from this SEMP planning process. The involvement of recognized experts is needed to establish a SEMP that is credible to the project manager and to secure the full commitment of the project team.

Systems Engineering Guide: SEMP
Figure 7

Organizational Learning

To achieve a paramount systems engineering performance, an organization must not only provide the best tools, methods, and techniques required to lead in systems engineering, but must also learn from its successes and failures. Hence, the SEG addresses selected ongoing and past experiences, including both successes, and failures[3]. To accomplish this, MSFC has teamed with the University of Alabama in Huntsville (UAH) to assess historical MSFC projects within the context of their respective systems engineering organization, planning, and implementation. This study has several objectives relevant to organizational learning. First, the study is developing correlations between systems engineering processes and practices employed on a project and that project's technical success.

Second, it will provide a library of case studies which may be referenced by engineers and managers, and which may be used in MSFC in-house systems engineering training. Ultimately, these lessons learned will be applied to on-going MSFC projects. The study also addresses personnel training specific to Systems Engineering & Integration (SE&I) at MSFC in particular space system contexts, and develops effective ways to tailor the standard SE&I processes described in NPR 7123. Clearly the type and scale of space system implies distinctions in the system engineering processes and practices. Systems engineering as implemented for the Ares Launch Vehicle, a large, complex space system, should certainly differ from that implemented for science payload flying on a sounding rocket. While the systems engineering processes would still be implemented for both systems, the methods by which they would be accomplished would differ. Through analysis of past projects, this study seeks to discover "best practices" for systems engineering for the differing scopes and scales of space systems developed by MSFC. Additionally, the study seeks to identify pitfalls to avoid – practices that may work well in one context but not another. These guidelines will be incorporated into the "processes, tools, & methods" resources described in the preceding section as they are identified.

Project success is determined in multiple dimensions, on the basis of technical, budget, schedule, and management criteria. The manner in which the 17 NPR-7123 prescribed systems engineering processes were implemented is determined on the basis of examination of the project's technical artifacts (e.g. project system engineering documents and records) and personal interviews with project team members. The study has to date completed assessments of the systems engineering implementations of two projects – the International Space Welding Experiment (ISWE) and the Space Shuttle Solid Rocket Motor (SRM). The ISWE was assessed largely to validate and refine the study methodology, while the Space Shuttle SRM represents the first full-scale assessment. Assessments are underway on several additional MSFC projects including the Chandra X-ray Observatory, Space Shuttle Main Engine, NASA X-37, International Space Station EXPRESS Rack, and Gravity Probe-B.

By creating an environment of organizational systems engineering "Learning" at MSFC in Space System Design, this communication infrastructure will enable MSFC system engineers, teams, management, and projects to communicate requirements and customer solutions effectively and efficiently across organizational and engineering boundaries. This will in turn enable planning and implementation of effective and efficient systems engineering processes for the myriad space system projects envisioned for MSFC.

Remarks

As systems and subsystem requirements become more complex in the pursuit of the exploration of space, advanced technology demands an integrated approach to the design and development of safe and successful space vehicles and their products. Safe and cost effective products of advanced technology require an iterative and integrated approach to the design of the end product. This iterative and integrated approach is not only applied to the integration of the hardware and software, it is just as applicable to the integration and satisfaction of the stakeholders and the customers, and the end users of the products and the maintenance of the product. It is equally applicable to the initial decisions made in determining the feasibility of the product, its cost, schedule, performance, risk, and the disposal of the product. Essentially, to design and construct a safe and affordable product, it must be engineered with quality throughout its Life Cycle. This is the vision of the Systems Engineering Guide development at MSFC. This vision is to enable, promote, and to communicate an environment in which this type of Systems Engineering activity will flourish for future programs and projects at NASA and MSFC.

References

1. INCOSE (International Council on Systems Engineering) "Systems Engineering Handbook", pp.12, June 1, 2004, Ver2a.
2. "NASA Systems Engineering Processes and Requirements", pp.14, NPR 7123.1A, March 26, 2007.
3. "NPR 7123.1A", pp.4c.
4. "NPR 7123.1A", pp.7